

Precision Measurement of Neutron Asymmetry A_1^n at Large x_{Bj}

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BNL Spin Discussion, May 21, Upton, NY

OUTLINE

- Introduction - Polarized DIS and Spin Structure Functions
- Theories about A_1^n
- Experiment E99-117
 - Experimental Setup
 - Jefferson Lab Hall A Polarized ^3He Target
 - Data Analysis – From ^3He to Neutron
- Preliminary Results
- Discussion, Summary and Outlook

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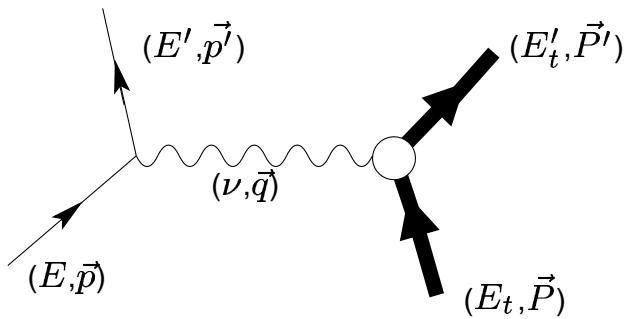
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Polarized Deep Inelastic Scattering

POLARIZED DIS



STRUCTURE FUNCTIONS

- Unpolarized Target:

$$\frac{d^2\sigma_{\uparrow\uparrow}}{d\Omega dE'} + \frac{d^2\sigma_{\uparrow\downarrow}}{d\Omega dE'} = \frac{8\alpha^2 E'^2}{mQ^4} [2 \sin^2 \frac{\theta}{2} F_1(x, Q^2) + \frac{m^2}{\nu} \cos^2 \frac{\theta}{2} F_2(x, Q^2)]$$

$$F_1(x, Q^2) = \frac{F_2(x, Q^2)(1 + \gamma^2)}{2x(1 + R(x, Q^2))}$$

- Longitudinally Polarized Target:

$$\frac{d^2\sigma_{\uparrow\uparrow}}{d\Omega dE'} - \frac{d^2\sigma_{\uparrow\downarrow}}{d\Omega dE'} = \frac{4\alpha^2 E'}{E\nu Q^2} [(E + E' \cos \theta) g_1(x, Q^2) - 2xm g_2(x, Q^2)]$$

- Transversely Polarized Target:

$$\frac{d^2\sigma_{\uparrow\Rightarrow}}{d\Omega dE'} - \frac{d^2\sigma_{\uparrow\Leftarrow}}{d\Omega dE'} = \frac{4\alpha^2 E'^2}{E\nu Q^2} \sin \theta [g_1(x, Q^2) + \frac{2Em}{\nu} g_2(x, Q^2)]$$

STRUCTURE FUNCTIONS IN QPM

Within the Quark-Parton Model,

$$F_1(x) = \frac{1}{2} \sum_i e_i^2 [q_i^\uparrow(x) + q_i^\downarrow(x)]$$

$$g_1(x) = \frac{1}{2} \sum_i e_i^2 [q_i^\uparrow(x) - q_i^\downarrow(x)]$$

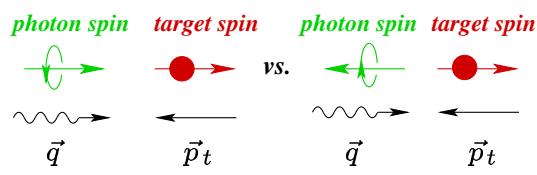
Ignoring quark mass effects,

$$g_2(x, Q^2) = g_2^{WW}(x, Q^2) + \bar{g}_2(x, Q^2)$$

$$g_2^{WW}(x, Q^2) = -g_1(x, Q^2) + \int_x^1 \frac{g_1(y, Q^2)}{y} dy$$

VIRTUAL PHOTON ASYMMETRIES

$$A_1 = \frac{\sigma_{\frac{1}{2}} - \sigma_{\frac{3}{2}}}{\sigma_{\frac{1}{2}} + \sigma_{\frac{3}{2}}}$$

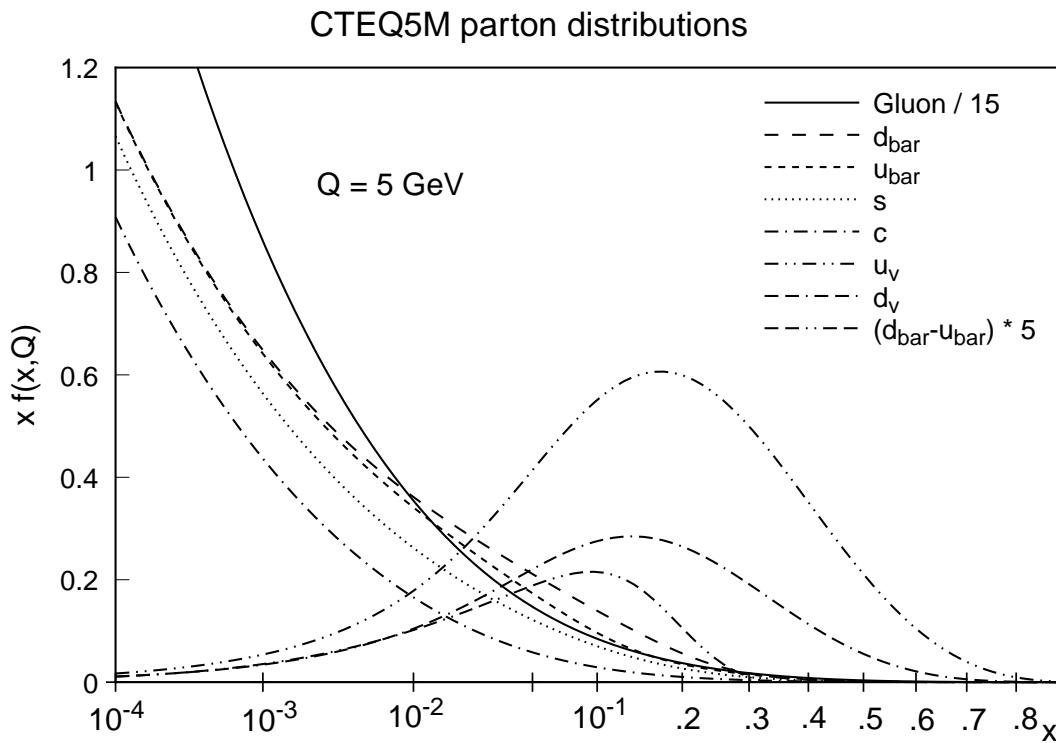


$$A_1(x, Q^2) = \frac{g_1(x, Q^2) - \gamma^2 g_2(x, Q^2)}{F_1(x, Q^2)}$$

A_1^n at high x_{Bj}

WHY AT HIGH x_{Bj} ?

- Valence quarks dominate;
- Constituent quark models
 - Is our understanding of valence quark picture correct?
- pQCD
 - how solid it is and to how low x it can apply;



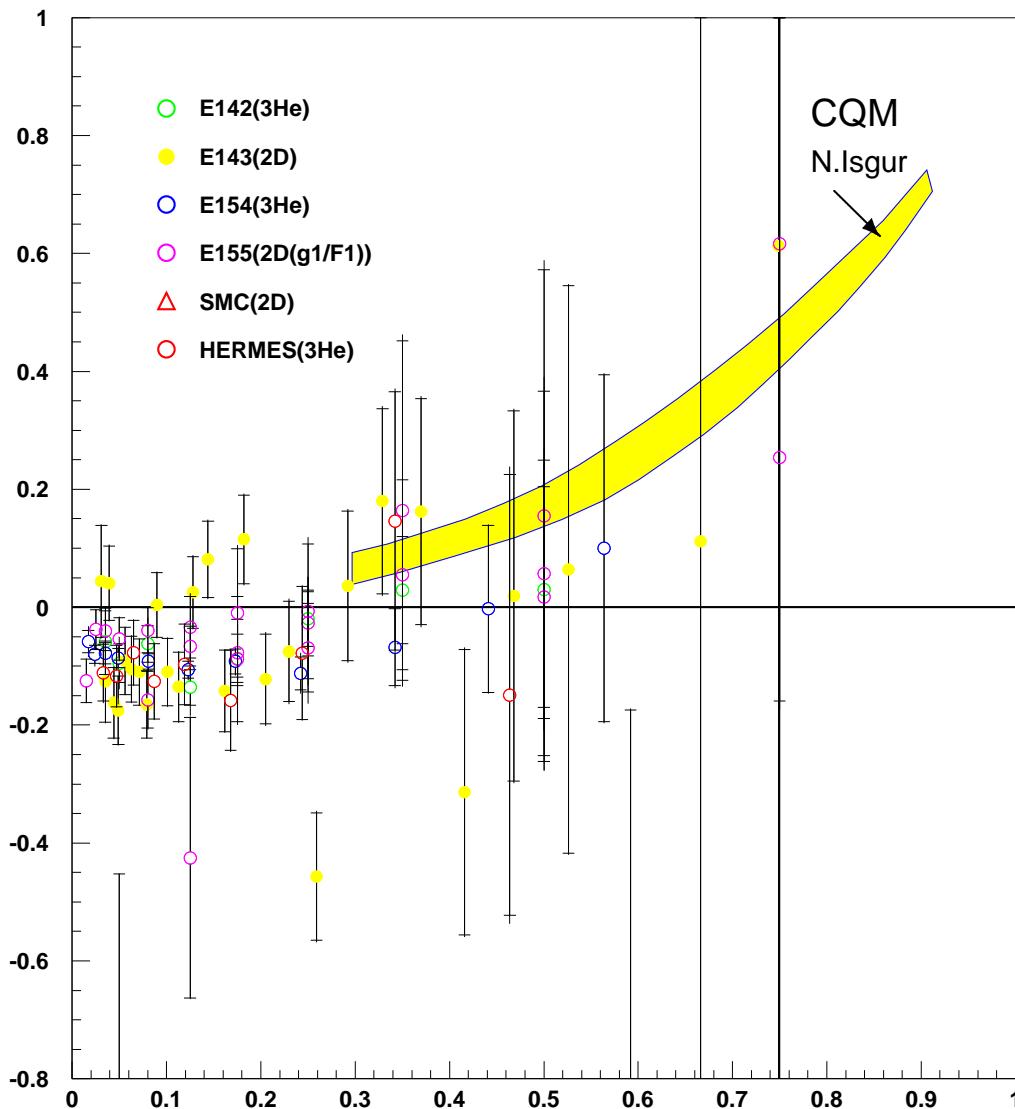
Theories about A_1^n

- SU(6): $A_1^n = 0$
- SU(6) Broken: $A_1^n \rightarrow 1$ as $x \rightarrow 1$;
- Constituent quark models (CQM): N.Isgur $A_1^n \rightarrow 1$ as $x \rightarrow 1$;
- pQCD at $Q^2 \rightarrow \infty$, $A_1^n \rightarrow 1$ as $x \rightarrow 1$;
- Statistical model, C.Bourrely, J. Soffer ;
- Duality: W. Melnitchouk;
- Chiral Quark-Soliton Model, H. Weigel, $A_1^n < 0$ for $x > 0.5$;
- Instanton Model, N.I.Kochelev, $A_1^n \sim 0$ or $A_1^n < 0$;

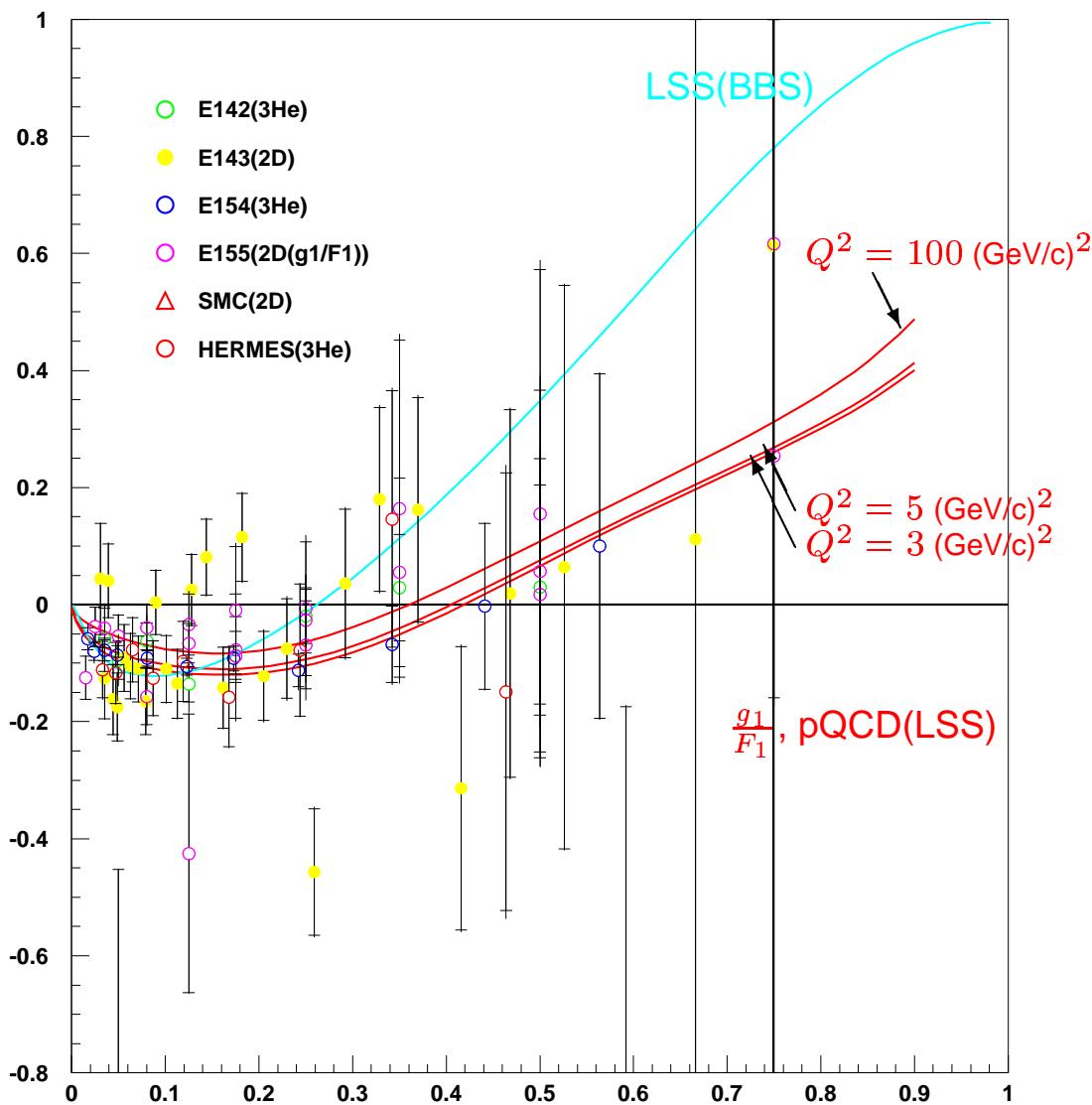
- CQM: N.Isgur, Phys.Rev. D59 (1999) 034013

- Hyperfine perturbed
- A (simple) parameterization: $\frac{d(x)}{u(x)} \approx \kappa(1-x)$ as $x \rightarrow 1$, $\kappa \approx 0.5 \sim 0.6$
 $c_A(x) = nx(1-x)^n$, $n = 2 \sim 4$
- $A_1^n(x) = \frac{4\Delta d_v(x) + \Delta u_v(x)}{4d_v(x) + u_v(x)}$ $A_1^p(x) = \frac{4\Delta u_v(x) + \Delta d_v(x)}{4u_v(x) + d_v(x)}$
- A_1^n and $A_1^p \rightarrow 1$ as $x \rightarrow 1$.

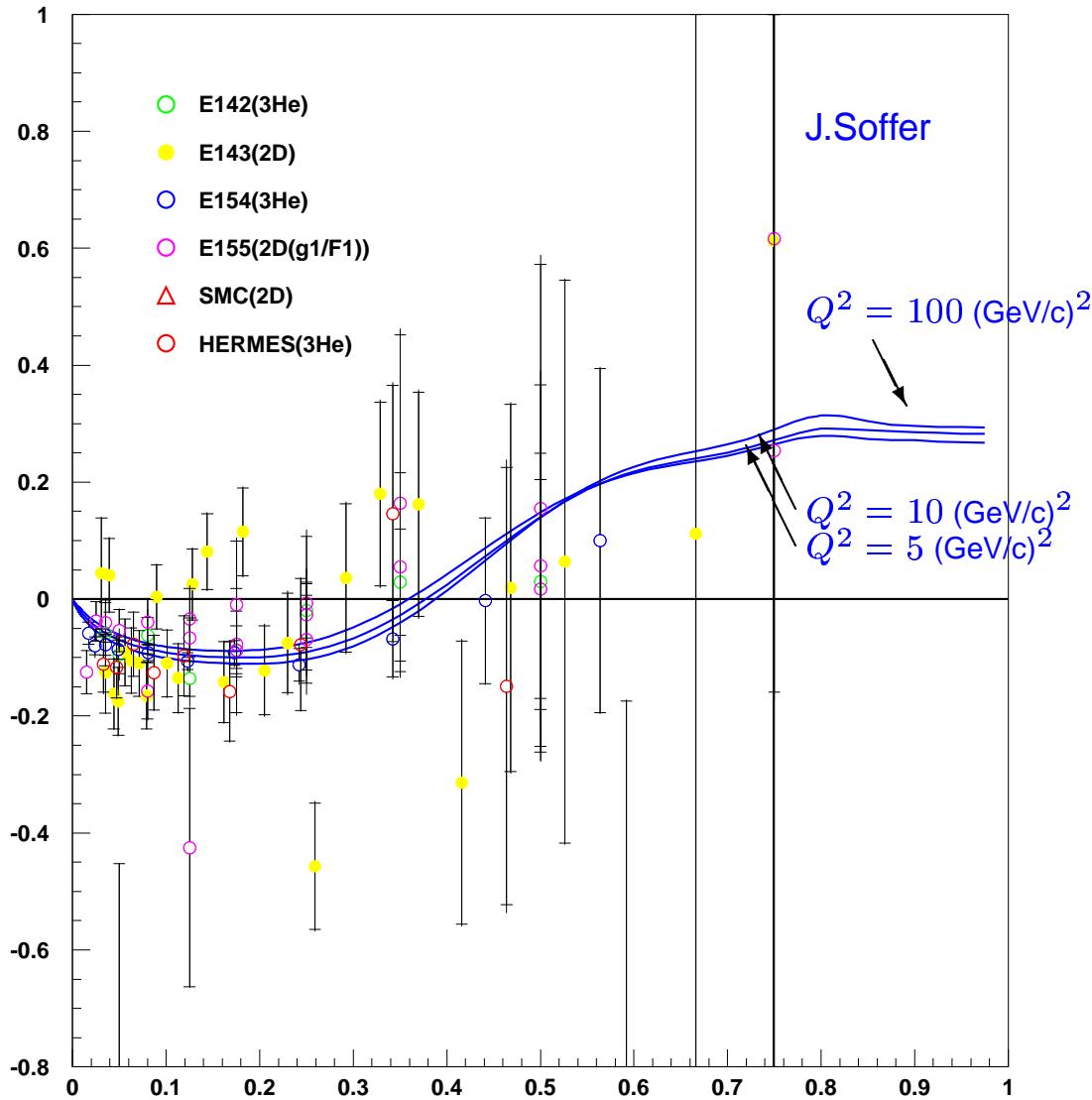
World data on A_1^n and prediction from CQM



- pQCD (LSS-BBS): E. Leader, A.V.Sidorov, D.B.Stamenov, [hep-ph/9708335](#)
 - Polarized & unpolarized parton densities by Brodsky, Burkhardt and Schmidt (BBS);
 - $\frac{\Delta u}{u} \rightarrow 1, \frac{\Delta d}{d} \rightarrow 1$ at $x \rightarrow 1$.
- pQCD (LSS2001): E. Leader, A.V.Sidorov, D.B.Stamenov, [hep-ph/0111267](#)
 - A new evaluation of NLO polarized parton densities in the nucleon;
 - calculation done for g_1/F_1 at $Q^2 = 3, 5, 100$ (GeV/c) 2 .

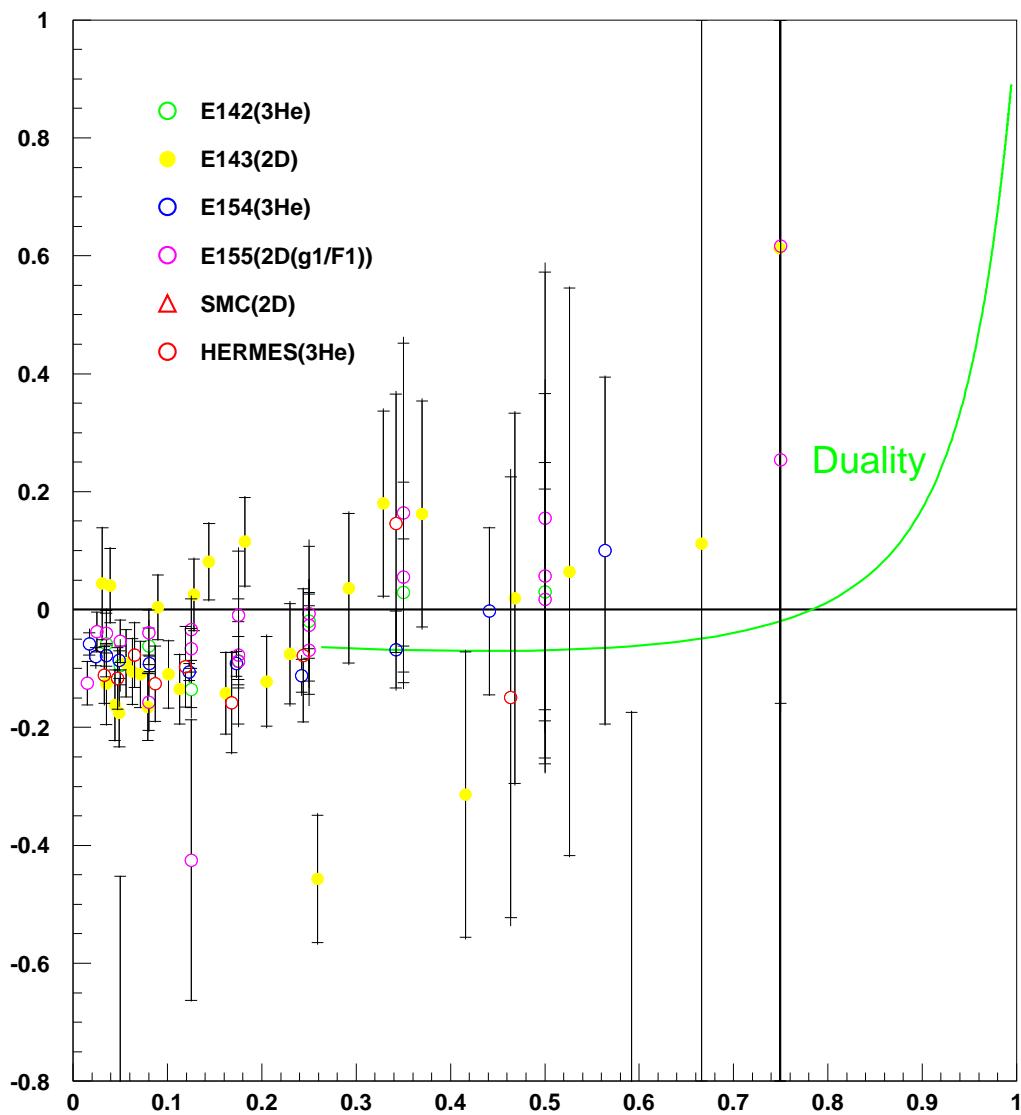
World data on A_1^n and pQCD predictions

- **Statistical Model:** C.Bourrely, J. Soffer, [hep-ph/0109160](#)
 - global NLO QCD analysis of unpolarized and polarized DIS data;
 - parton distributions constructed in a statistical physical picture of the nucleon:
$$p(x) \propto [\exp(x - X_{0p})/\bar{x} \pm 1]^{-1}$$
- calculation done for A_1 at $Q^2 = 5, 10, 100 (\text{GeV}/c)^2$, ($g_2 = g_2^{ww}$)

World data on A_1^n and Soffer's statistical model

- **Duality:** W. Melnitchouk, Phys. Rev. Lett. **86**, 35 (2001)

- local quark-hadron duality;
- predict $x \sim 1$ behavior of A_1 from available data on G_E, G_M ;

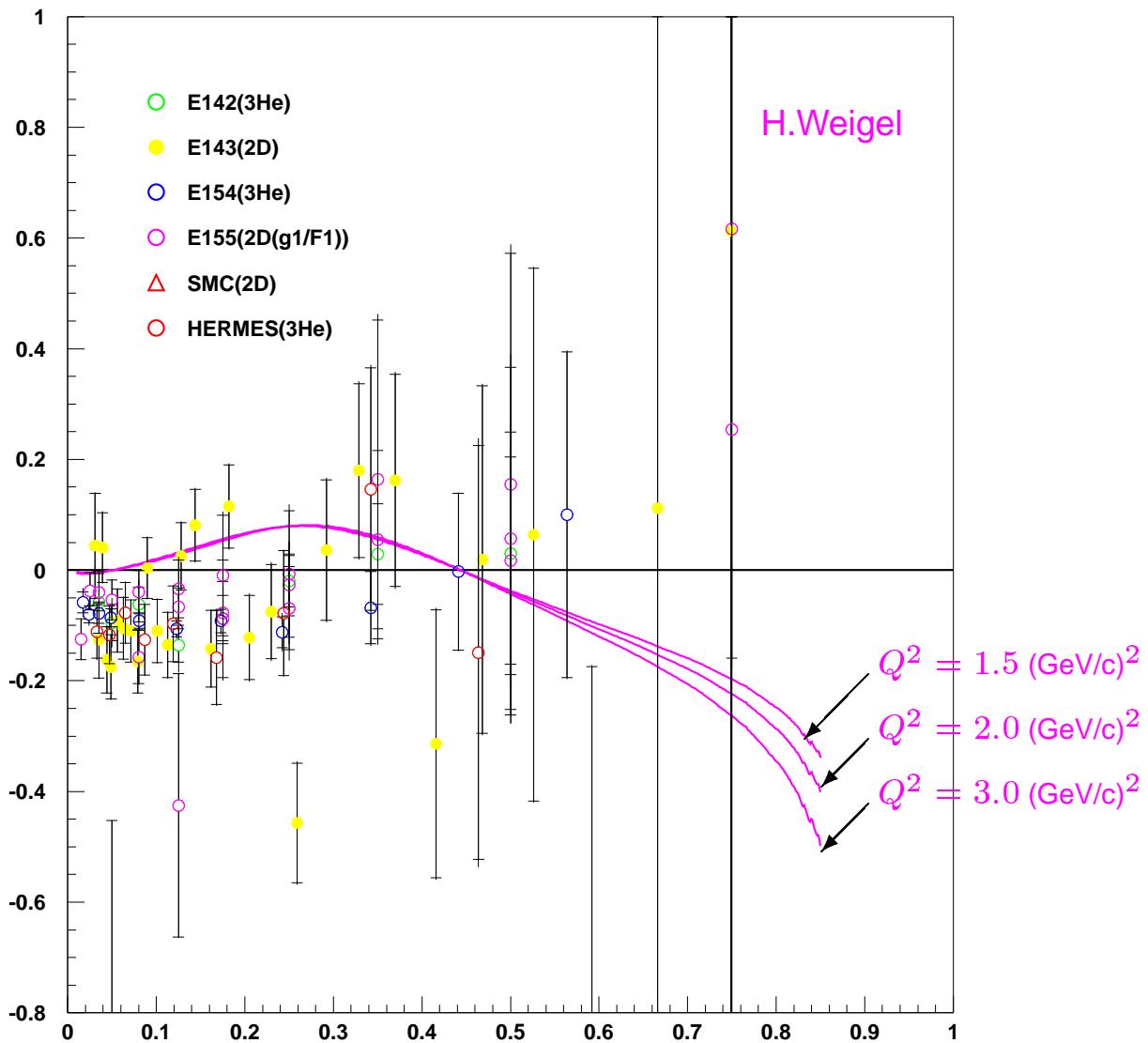
World data on A_1^n , Prediction from Duality

- Chiral Quark-Soliton Model:

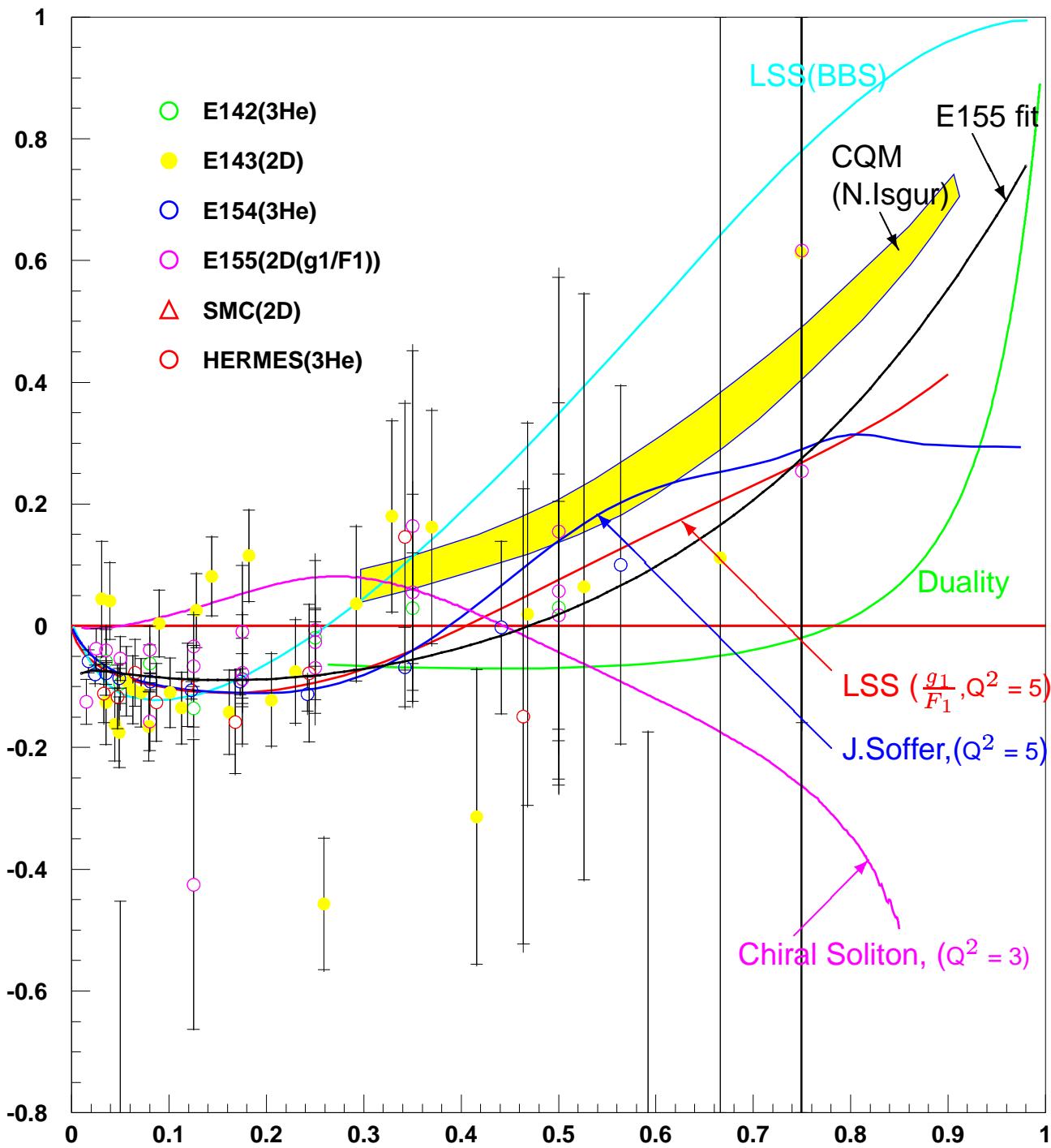
H.Weigel, L.Gamberg and H.Reinhardt, Phys. Lett. **B399**, 287 (1997), Phys. Rev. D**55**, 6910 (1997).

- Two flavor chiral soliton approach to baryons, based on the Bosonized Nambu-Jona-Lasinio (NJL) model;
- Model degrees of freedom are effective constituent quarks;
- Tentative calculation done for $\frac{g_1}{F_1}$ at $Q^2=1.5, 2.0, 3.0 \text{ (GeV/c)}^2$.

World data on A_1^n and chiral quark-soliton model



A_1^n World Data and Theoretical Predictions



Experiment E99-117

MEASURED A_1^n AT

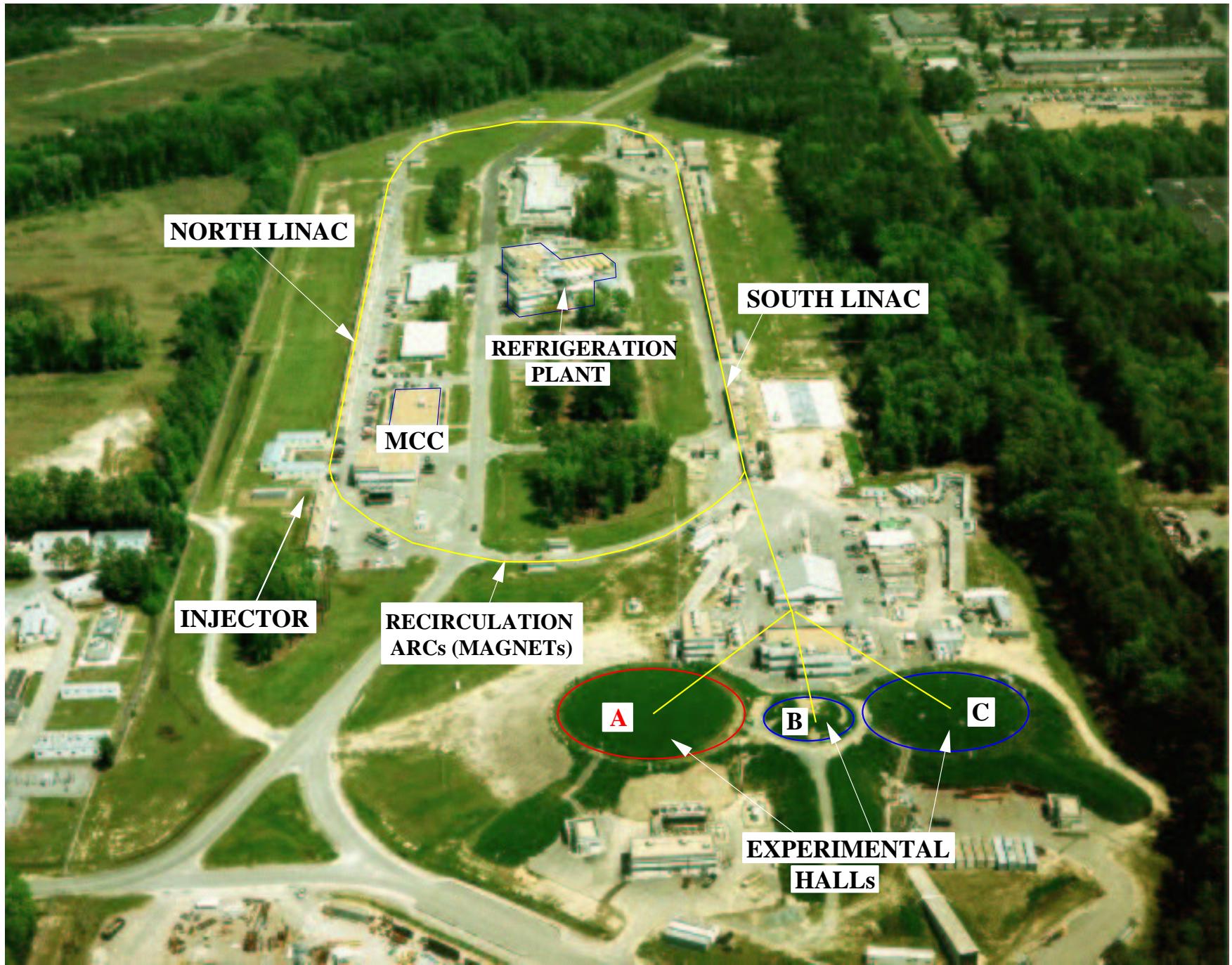
x_{Bj}	0.331	0.474	0.609
Q^2 (GeV/c) ²	2.738	3.567	4.887
W^2 (GeV/c) ²	6.426	4.846	4.023

through e^- asymmetries A_{\parallel} and A_{\perp} in inclusive $\vec{e}^- - {}^3\vec{He}$ DIS;

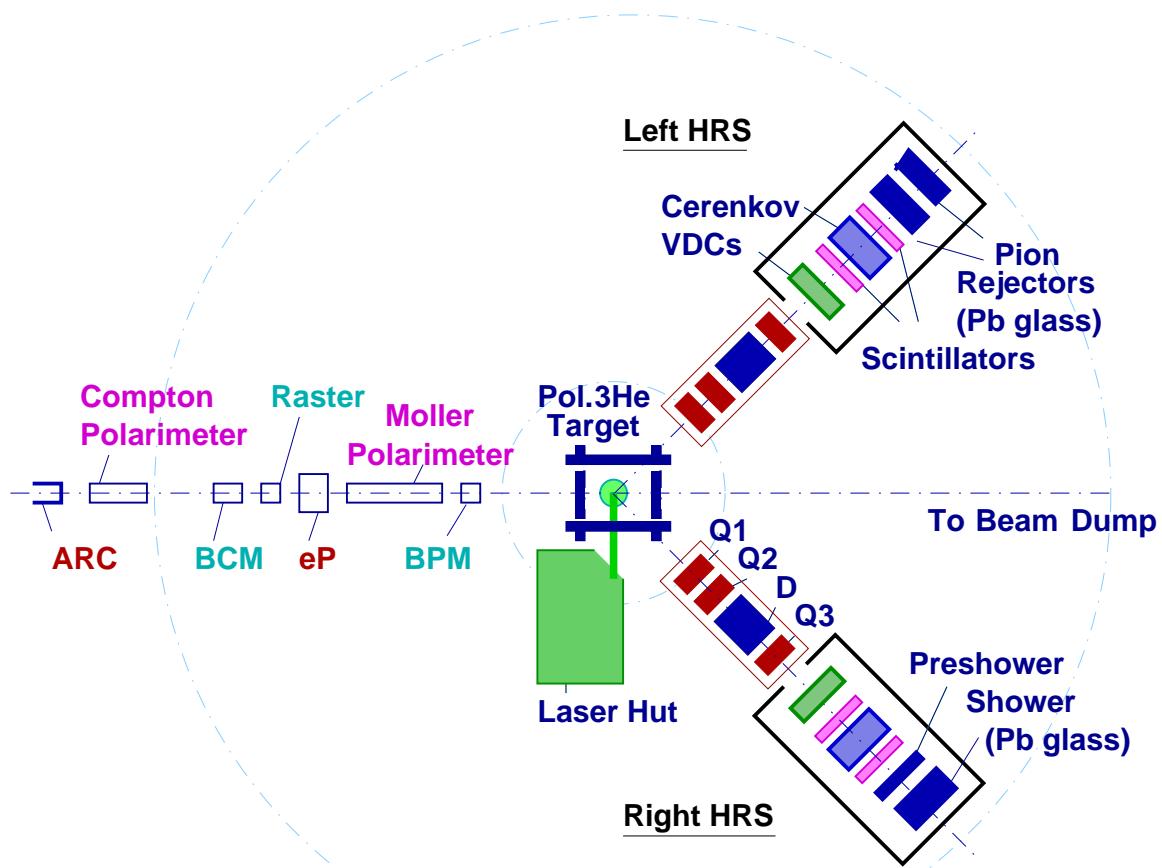
EXPERIMENTAL SETUP

- Jefferson Lab(JLab) polarized e^- beam, 5.734 GeV, $P_{beam} = 81\%$, $12 \mu\text{A}$
- Hall A polarized 3He target, ~ 10 atm, $P_{targ} = 40\%$
- Two Hall A High Resolution Spectrometers (HRS) at symmetric positions

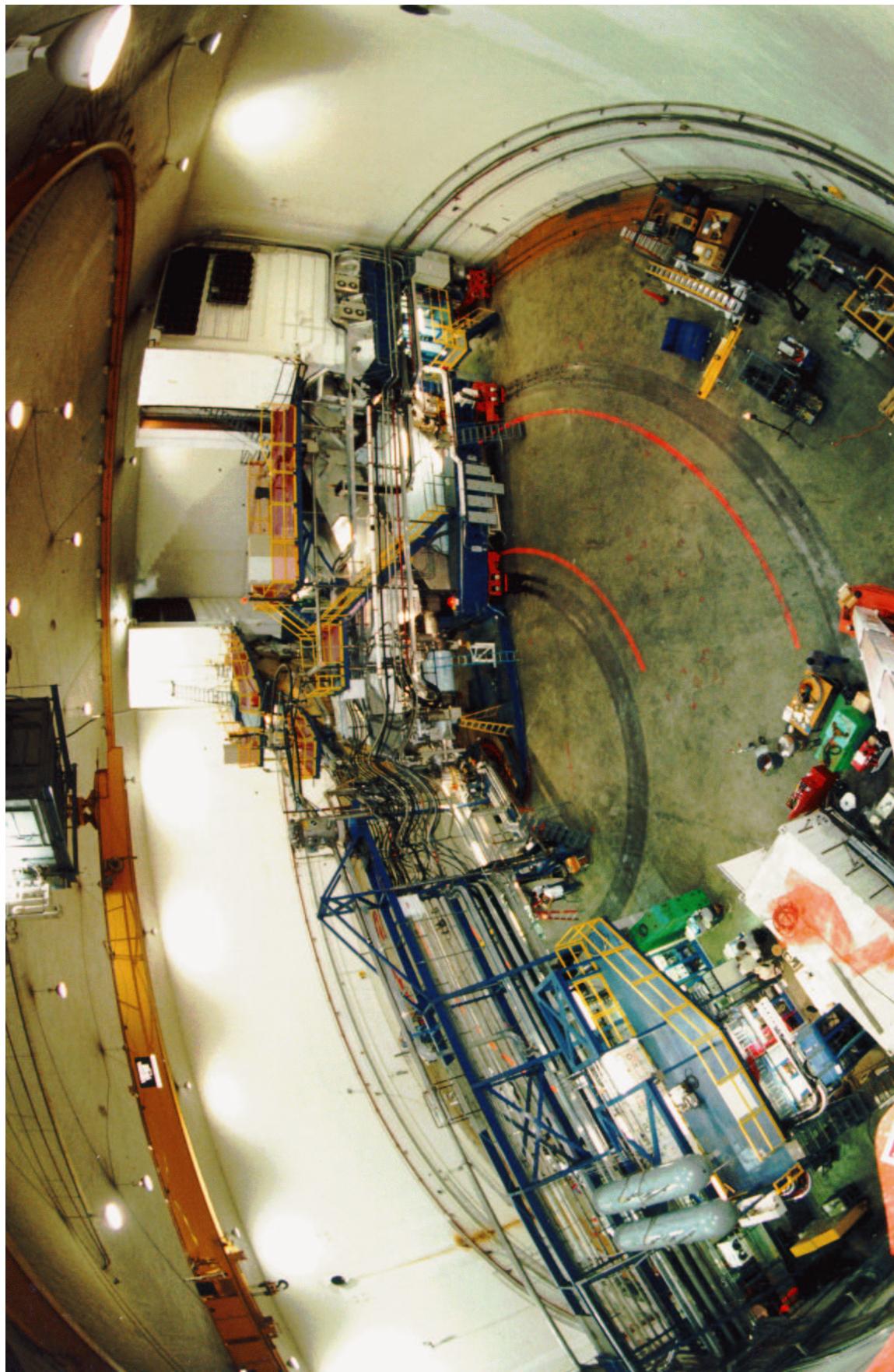
THE JEFFERSON LAB ACCELERATOR



EXPERIMENTAL HALL A



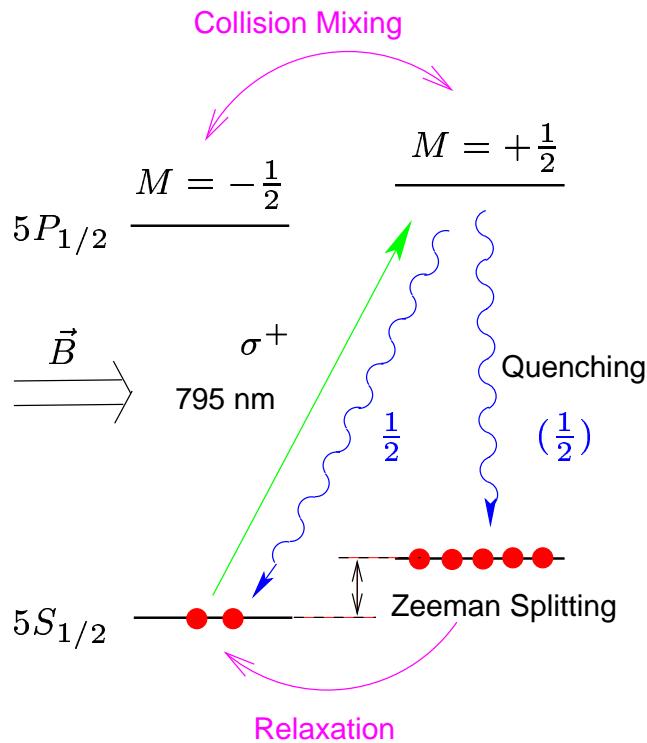
- Two VDCs for tracking;
- Sets of scintillators for triggering on charged particles;
- Gas cherenkov detector for pion rejection;
- Two layers of lead glass counters for additional PID;
- *Pion rejection efficiency:* better than 10^{-4} with electron efficiency 99%.



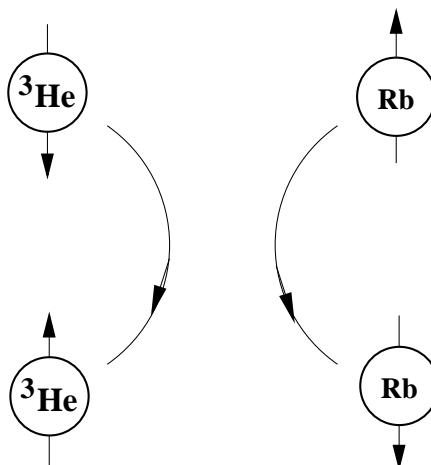
Polarized 3He Target

PRINCIPLE OF POLARIZING

- Optical pumping of Rb by circularly polarized light

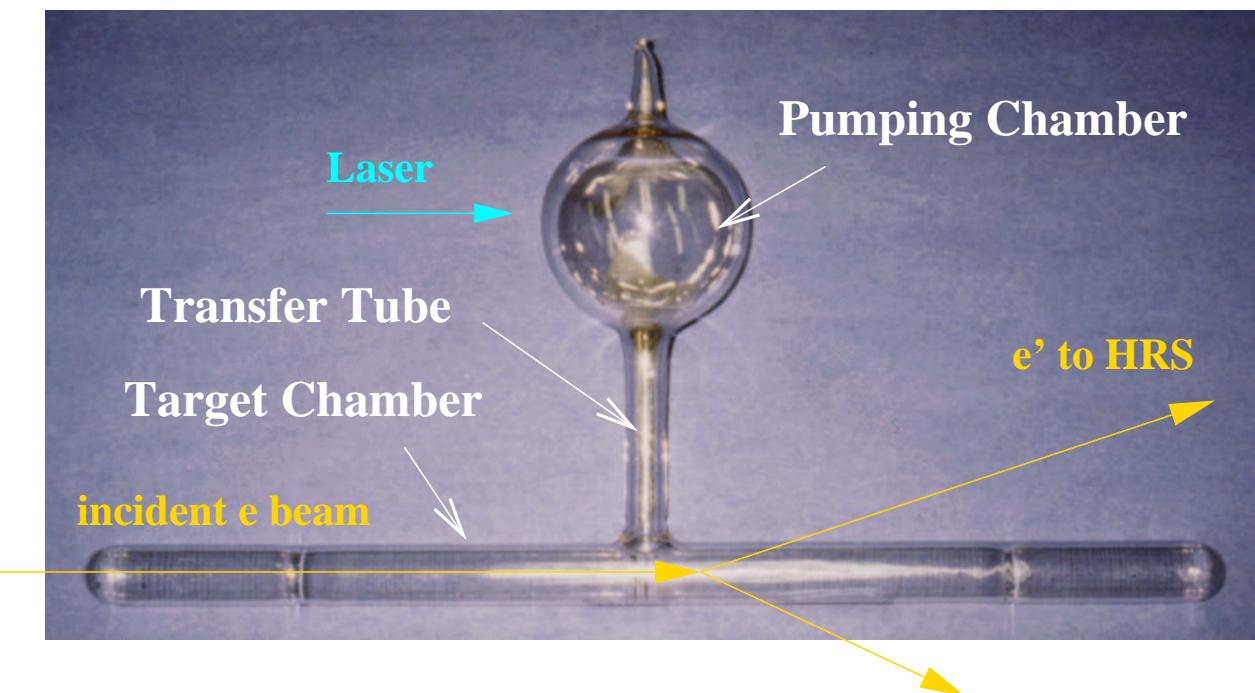


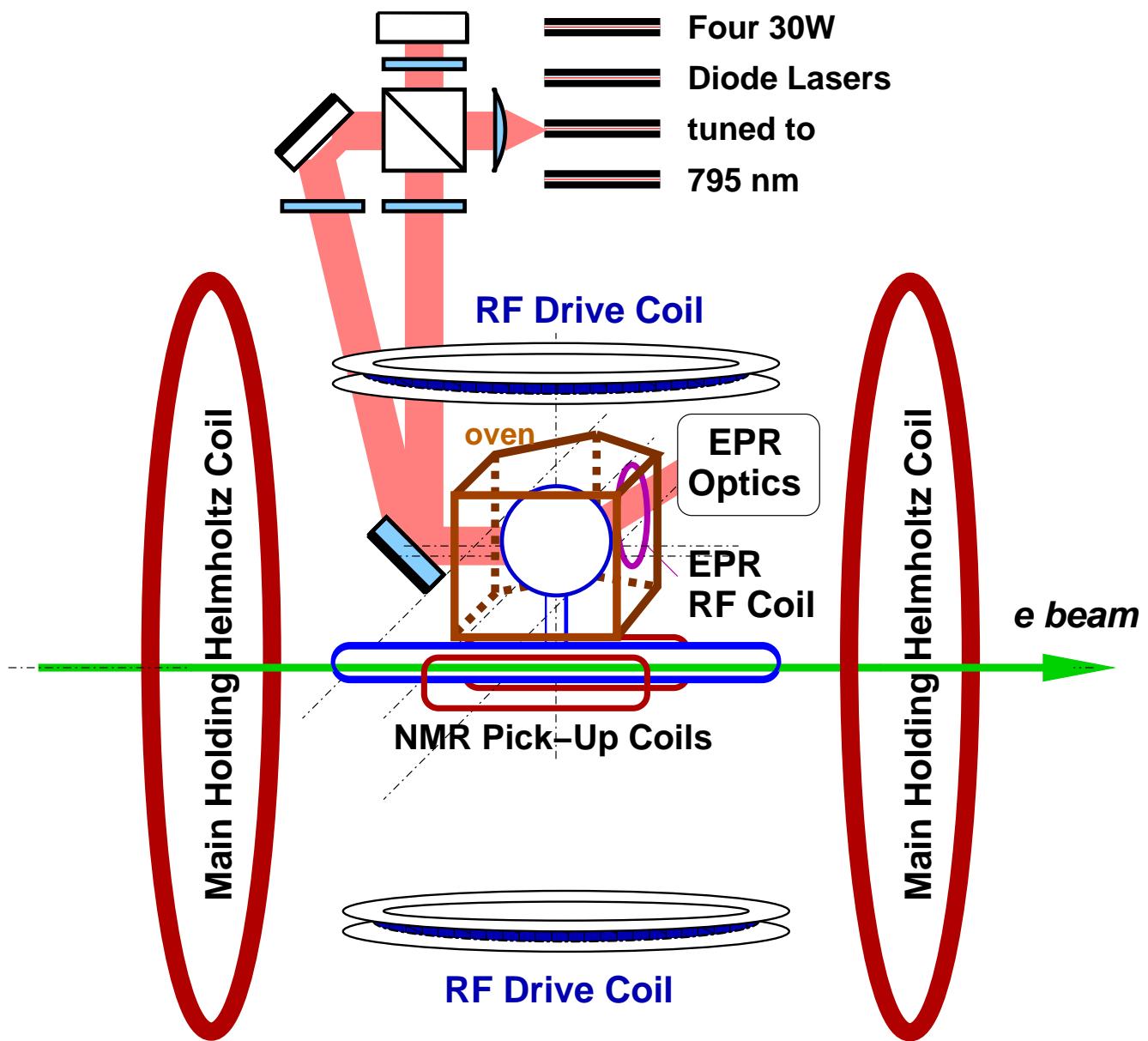
- Spin exchange through Rb- 3He collisions



THE CELL

- Cell density: $7.5 \sim 10$ amg.
- Maximum polarization: $\sim 40\%$ (in beam) - NMR, EPR Polarimetries
- Cell lifetime: $\Gamma = \Gamma_{He} + \Gamma_{wall} + \Gamma_{beam} + \Gamma_{\Delta B}$
 $\sim (40)^{-1} = (744/[He])^{-1} (90)^{-1} (655/I)^{-1} (1700)^{-1}$ (hours) $^{-1}$
- Cell end windows $100\mu m$, wall thickness ~ 130 mm
- Polarization diffusion: $P_p - P_t \sim 1\%$



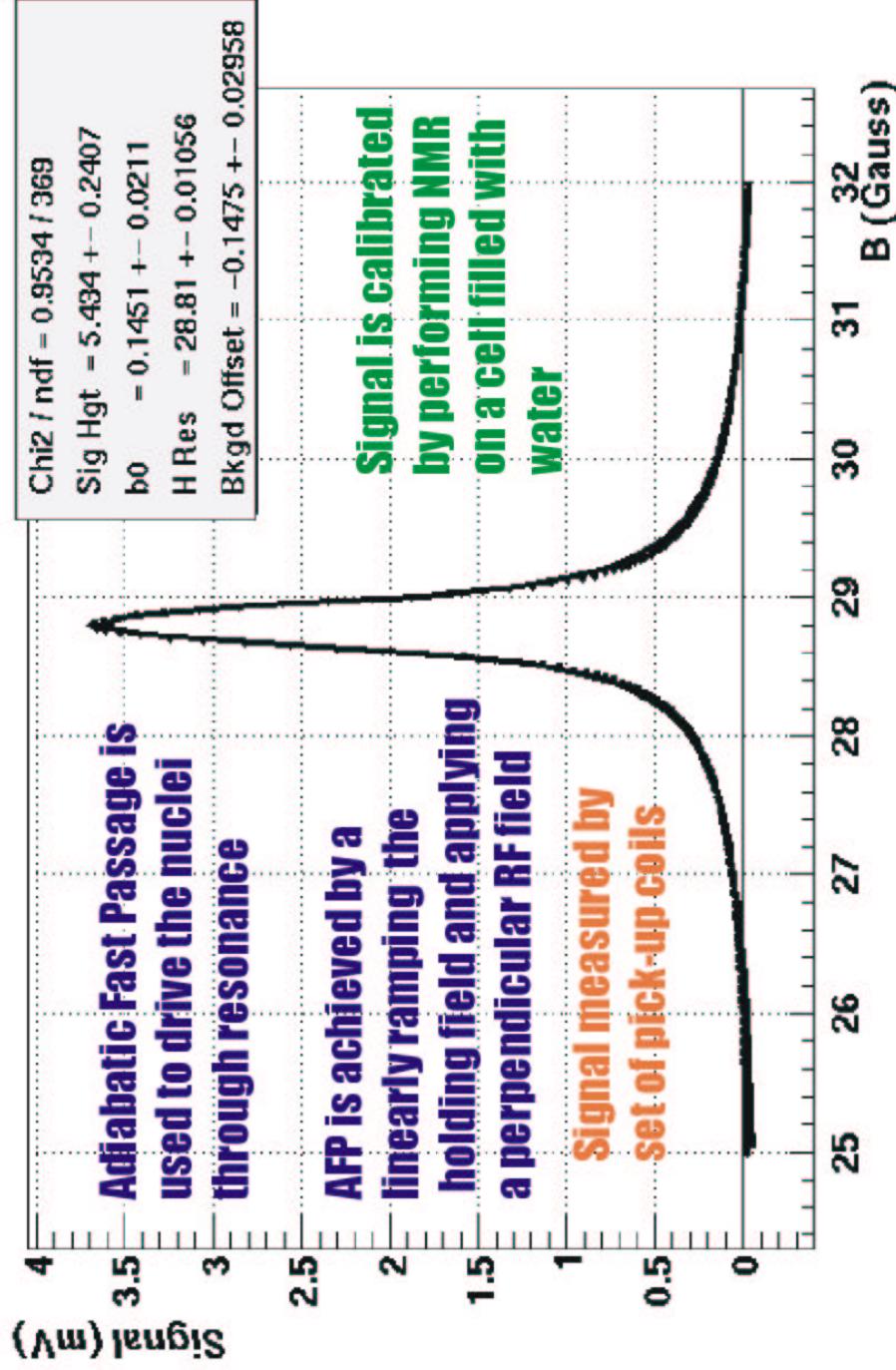
TARGET SETUP

NMR POLARIMETRY (K.Kramer, PST2001)

Target Polarimetry using NMR

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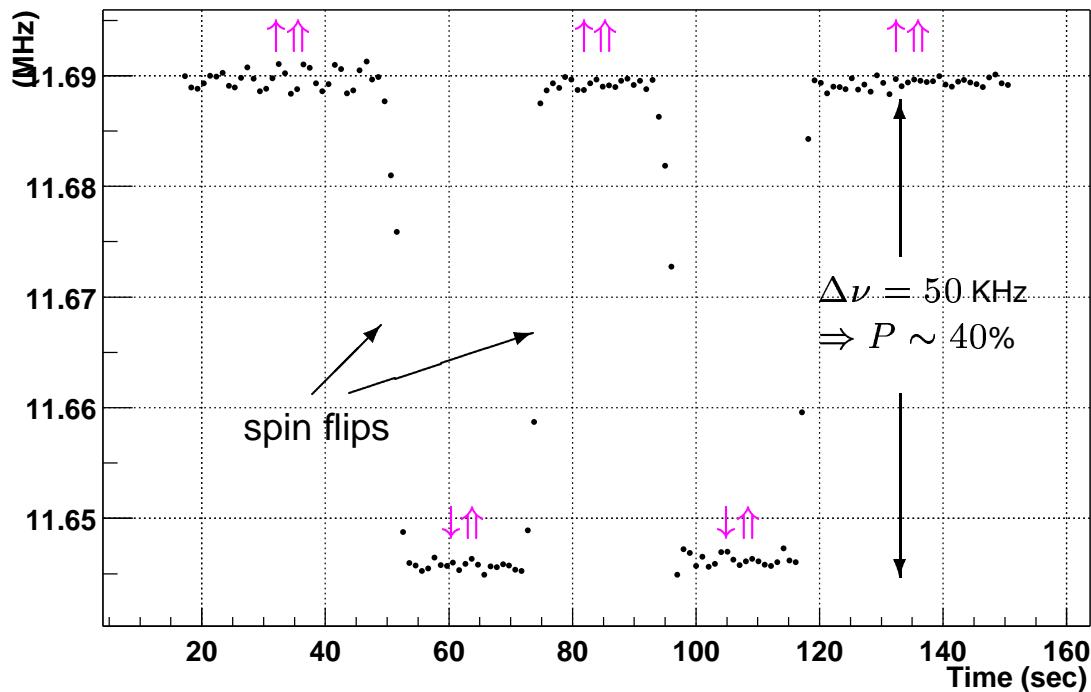
Gore-X Up-10:53am-15 Jun 2001



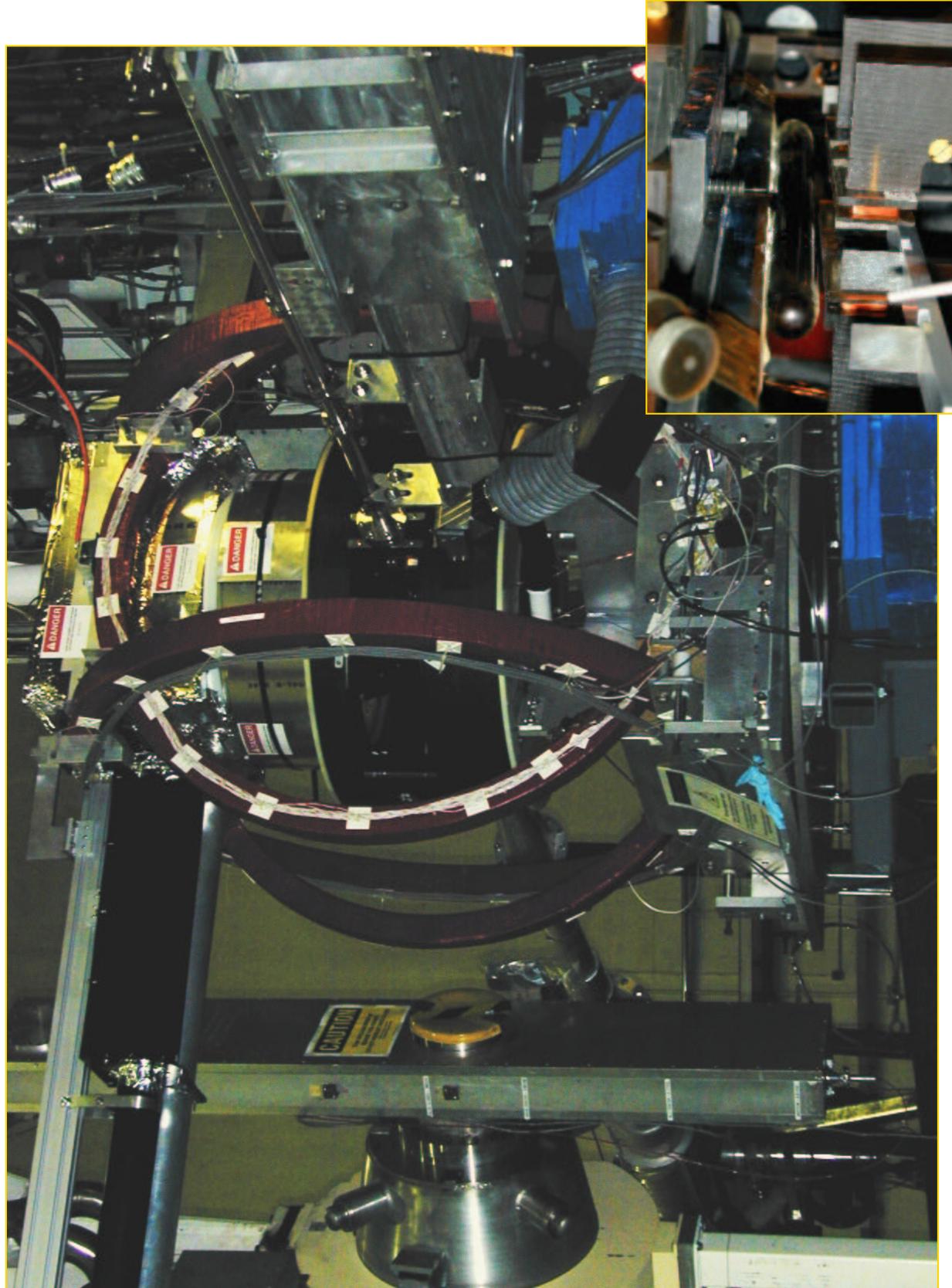
EPR POLARIMETRY

- Rb Zeeman splitting \propto Magnetic field magnitude \vec{B} ;
- $P_3 He$ induce a small $\vec{B}_{^3He}$, $\vec{B} = \vec{B}_{^3He} + \vec{B}_{main}$;
- Measure Rb resonance frequency shift due to $P_3 He$

EPR Spectrum AFP6_4_5_23am.dat

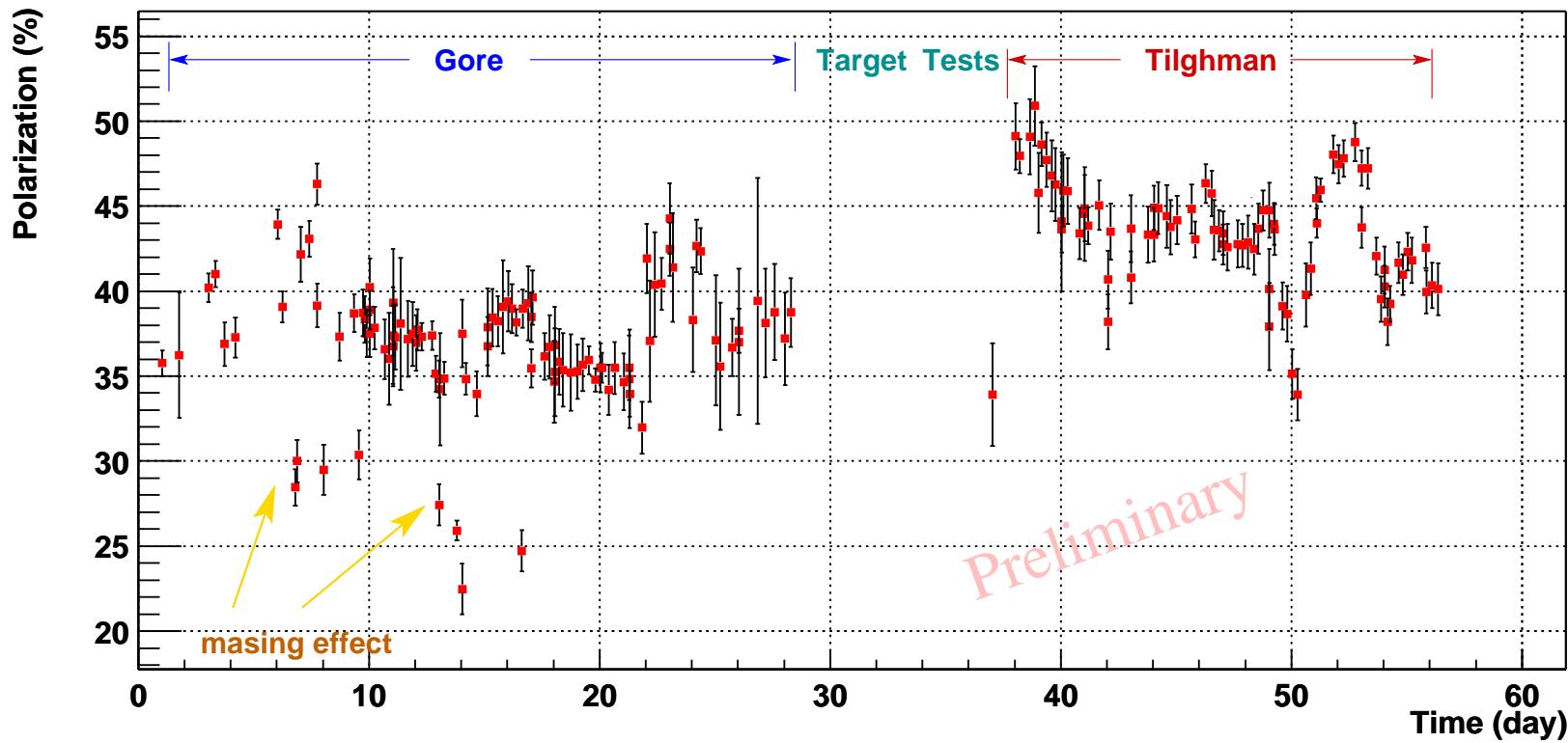


TARGET IN SITU



Polarized ^3He Target Performance During E99–117

Cell Name	Field direction	0°	180°	270°
Gore	June 06 ~ July 03	37%	35%	43%
Tilghman	July 13 ~ July 31	45%	43%	39%



Asymmetry Analysis

ELECTRON ASYMMETRIES

$$A_{raw} = \frac{N^+/Q^+ - N^-/Q^-}{N^+/Q^+ + N^-/Q^-}$$

$$A_{\parallel, \perp} = \frac{A_{raw}}{f P_b P_t}$$

${}^3\text{He}$ ASYMMETRIES

$$A_1 = \frac{A_{\parallel}}{D(1 + \eta\xi)} - \frac{\eta A_{\perp}}{d(1 + \eta\xi)}$$

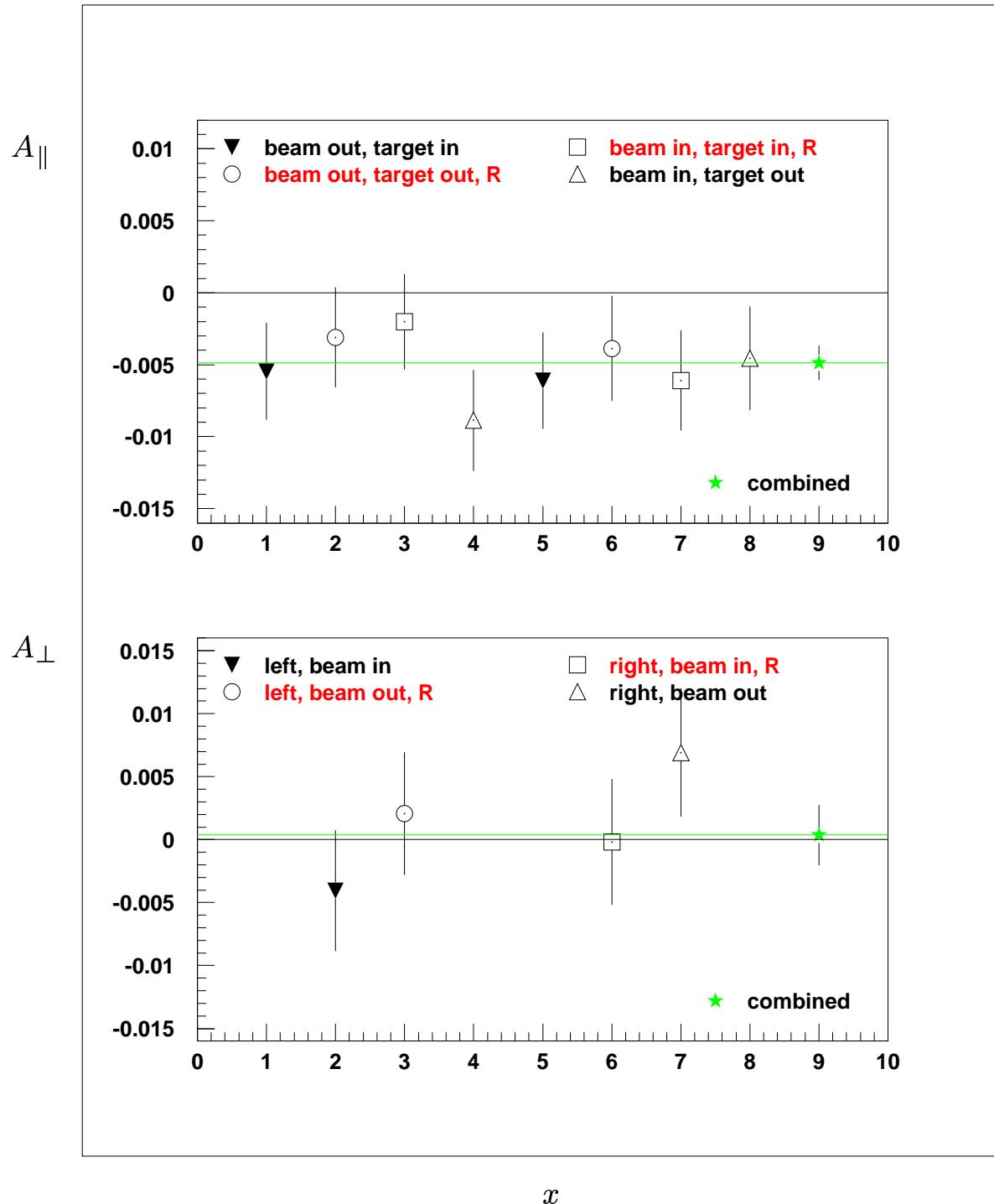
$$A_2 = \gamma \left\{ \frac{1 - \frac{y}{2}}{D'} A_{\parallel} + \frac{1}{D'} \left[\tan(\theta/2) + \frac{y}{2 \sin \theta} \frac{1 + (1 - y) \cos \theta}{1 - y} \right] A_{\perp} \right\}$$

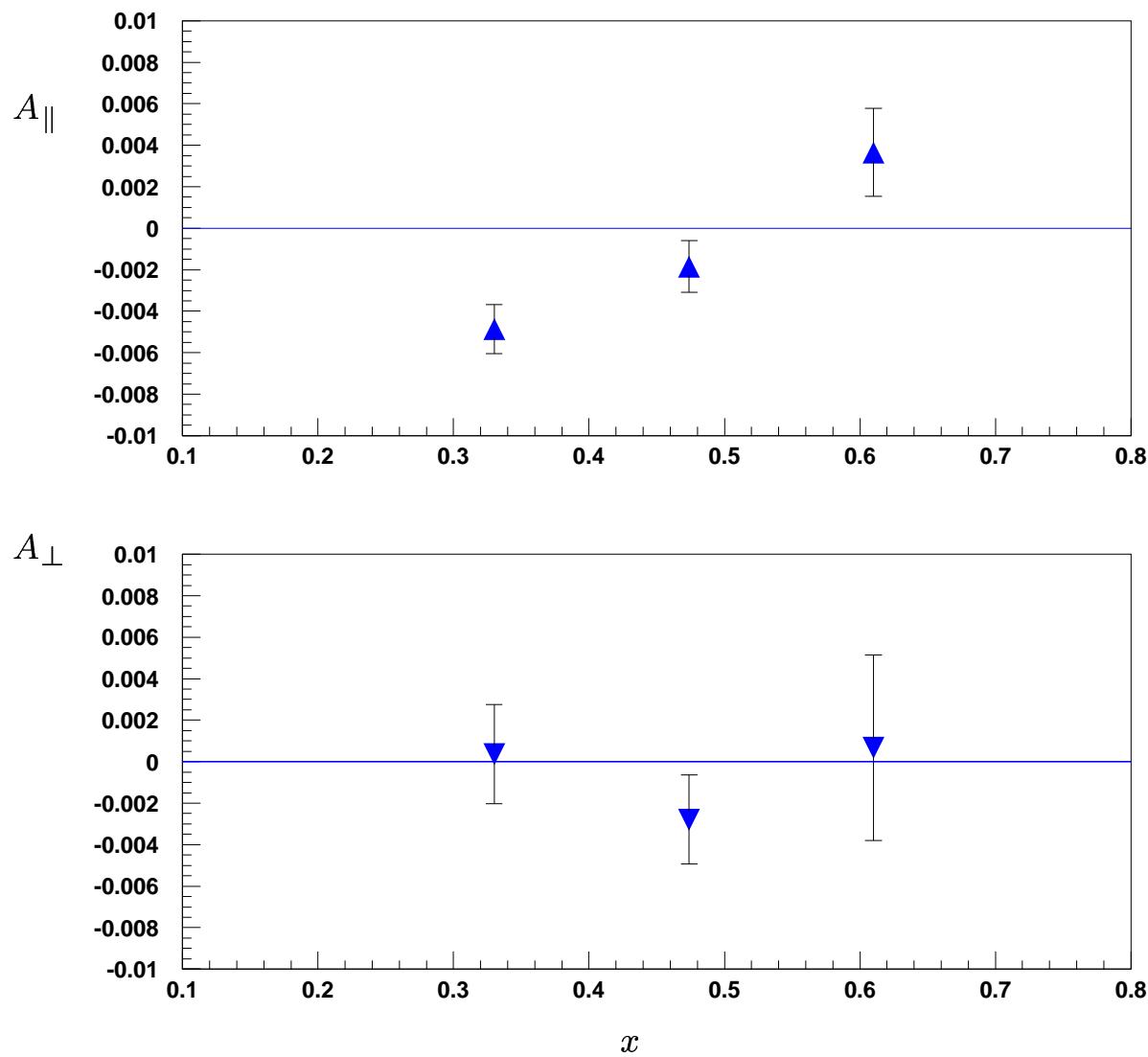
$$g_1(x, Q^2) = \frac{F_1(x, Q^2)}{D'} \left[A_{\parallel} + \tan(\theta/2) \cdot A_{\perp} \right]$$

$$g_2(x, Q^2) = \frac{F_1(x, Q^2)}{2D' y \sin \theta} \left[\frac{E + E' \cos \theta}{E'} A_{\perp} - \sin \theta \cdot A_{\parallel} \right]$$

Asymmetries

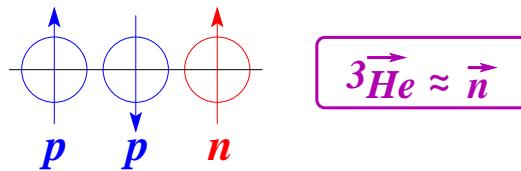
${}^3\text{He}$ RAW ASYMMETRIES

 x

${}^3\text{He}$ PHYSICS ASYMMETRIES

From ${}^3\text{He}$ to Neutron

${}^3\vec{\text{He}}$ AS EFFECTIVE \vec{n}



CONVOLUTION APPROACH

Ciofi degli Atti et.al., Phys.Rev.**C48**, 968(1993); Phys. Lett., **B404**, 223(1997)

- ${}^3\text{He}$ consists S, S', D
- Three body calculation using Fadeev wavefunction

$$\begin{aligned}\tilde{g}_1^n &= \frac{1}{\rho_n} (g_1^{{}^3\text{He}} - 2\rho_p g_1^p) \\ \tilde{A}_1^n &= \frac{W_1^{{}^3\text{He}}}{W_1^n} \frac{1}{\rho_n} (A_1^{{}^3\text{He}} - 2 \frac{W_1^p}{W_1^{{}^3\text{He}}} \rho_p A_1^p)\end{aligned}$$

COMPLETE ANALYSIS

F. Bissey et. al., [hep-ph/0109069](#)

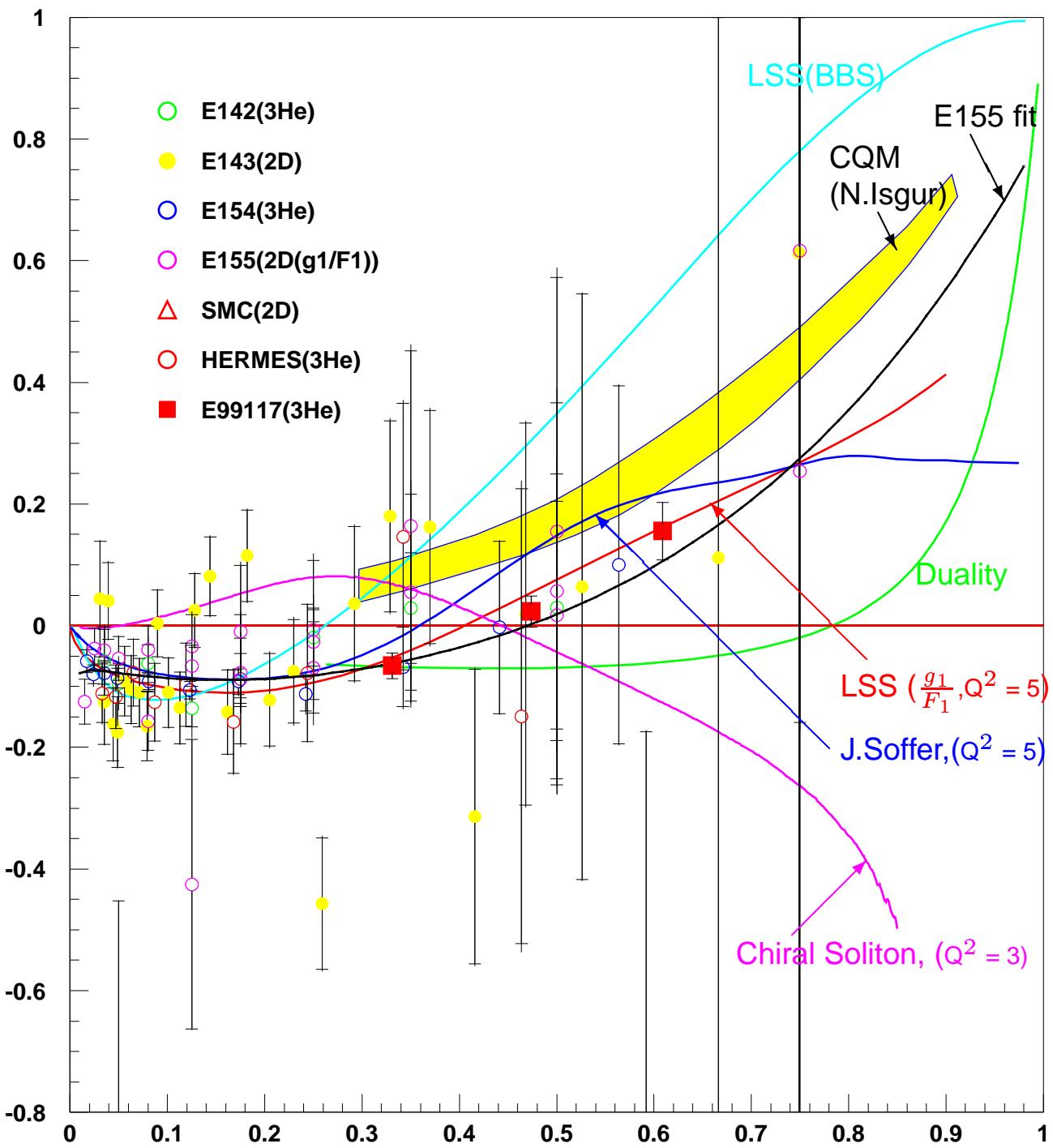
- S, S', D, Δ isobar in ${}^3\text{He}$ wavefunction

$$A_1^n = \frac{F_2^{{}^3\text{He}}}{P_n F_2^n (1 + \frac{0.056}{P_n})} [A_1^{{}^3\text{He}} - 2 \frac{F_2^p}{F_2^{{}^3\text{He}}} P_p A_1^p (1 - \frac{0.014}{2P_p})]$$

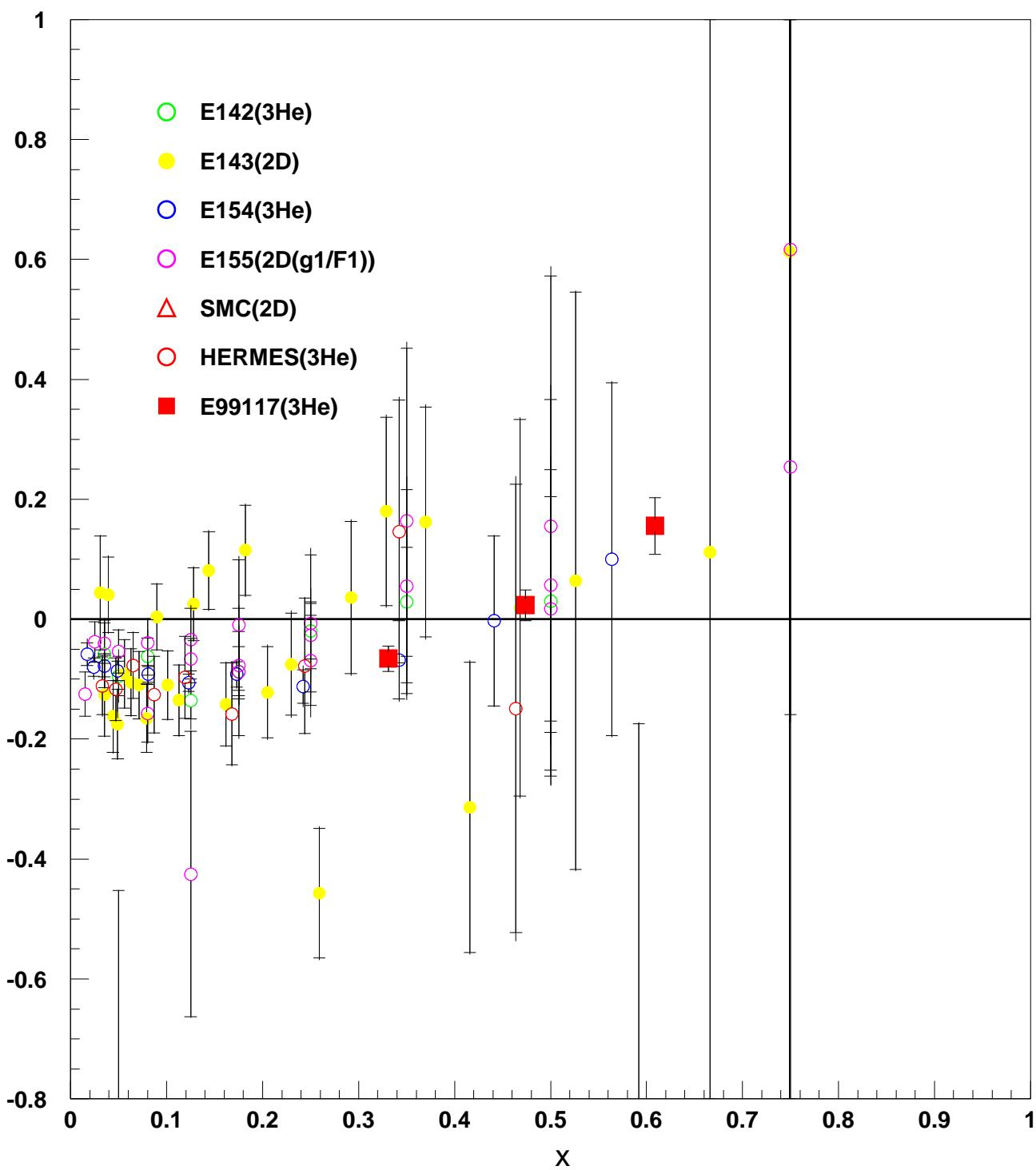
OTHER INPUTS

- $R(x, Q^2)$ - E143, K. Abe et. al., hep-ex/9808028
- F_2^p, F_2^D - NMC95, M. Arneodo et. al., hep-ph/9509406,
- EMC $F_2^{^3He} = \mathcal{R}^{^3He}(2F_2^p + F_2^n)$, $F_2^n = \frac{F_2^D}{\mathcal{R}^D} - F_2^p$, W. Melnitchouk, pri.comm.
- Effective nucleon polarization P_p, P_n
 - $P_p = -0.028 \pm 0.004, P_n = 0.86 \pm 0.02$
C. Ciofi degli Atti et.al., *Phys. Rev.* **C48**, R968(1993)
 - $P_p = -0.021, P_n = 0.879$
PEST5, F. Bissey et. al., *Phys. Rev.* **C64**, 024004(2001)
 - $P_p = -0.018, P_n = 0.897$
CD-Bonn2000 + TM (Tucson-Melbourne) 3NF, A. Nogga, Ph.D. thesis, (2001)
- A_1^p - E155 fit, P. L. Anthony et. al., *Phys. Lett.* **B493**:19-28,(2000) (hep-ph/0007248)
- g_2 , using g_2^{ww} (E155x)

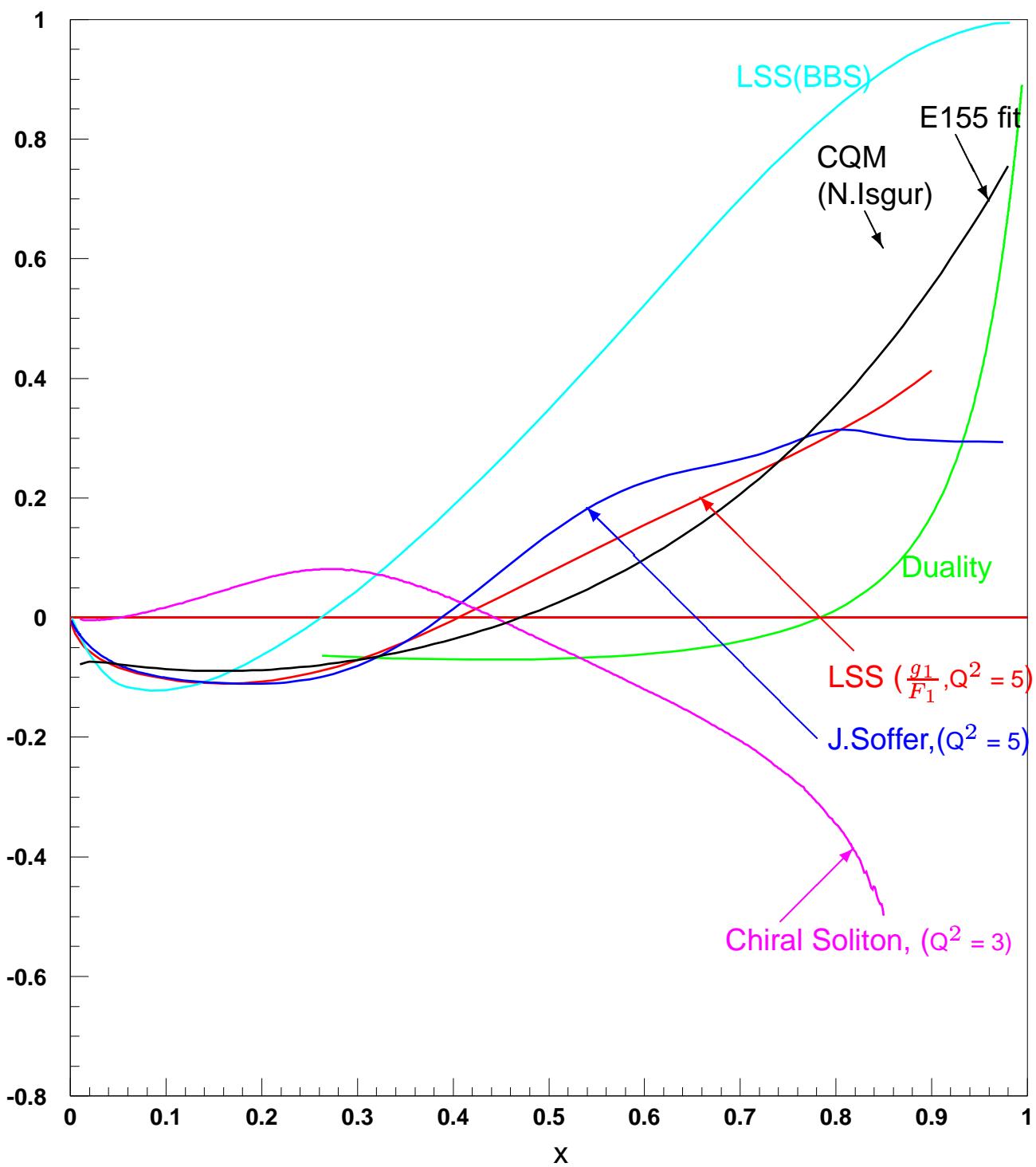
A_1^n Preliminary Result



A_1^n Preliminary Result



A_1^n Preliminary Result



Error Analysis

STATISTICS

- $\Delta A_1^n = 5\%$ at $x = 0.61$;

EXPERIMENTAL SYSTEMATICS

- Beam energy: 5.734 GeV, $\frac{\Delta E_b}{E_b} < 5 \times 10^{-4}$;
- Spectrometer momentum: $\frac{\Delta E_e}{E_e} < 5 \times 10^{-4}$;
- Spectrometer angle: $\Delta\theta_e < 0.1^\circ$;
- Beam polarization: 81%, $\frac{\Delta P_b}{P_b} < 3\%$;
- Target polarization: 40%, $\frac{\Delta P_t}{P_t} < 4\%$;
- Target spin orientation: $\Delta\theta_{targ} < 1^\circ$;

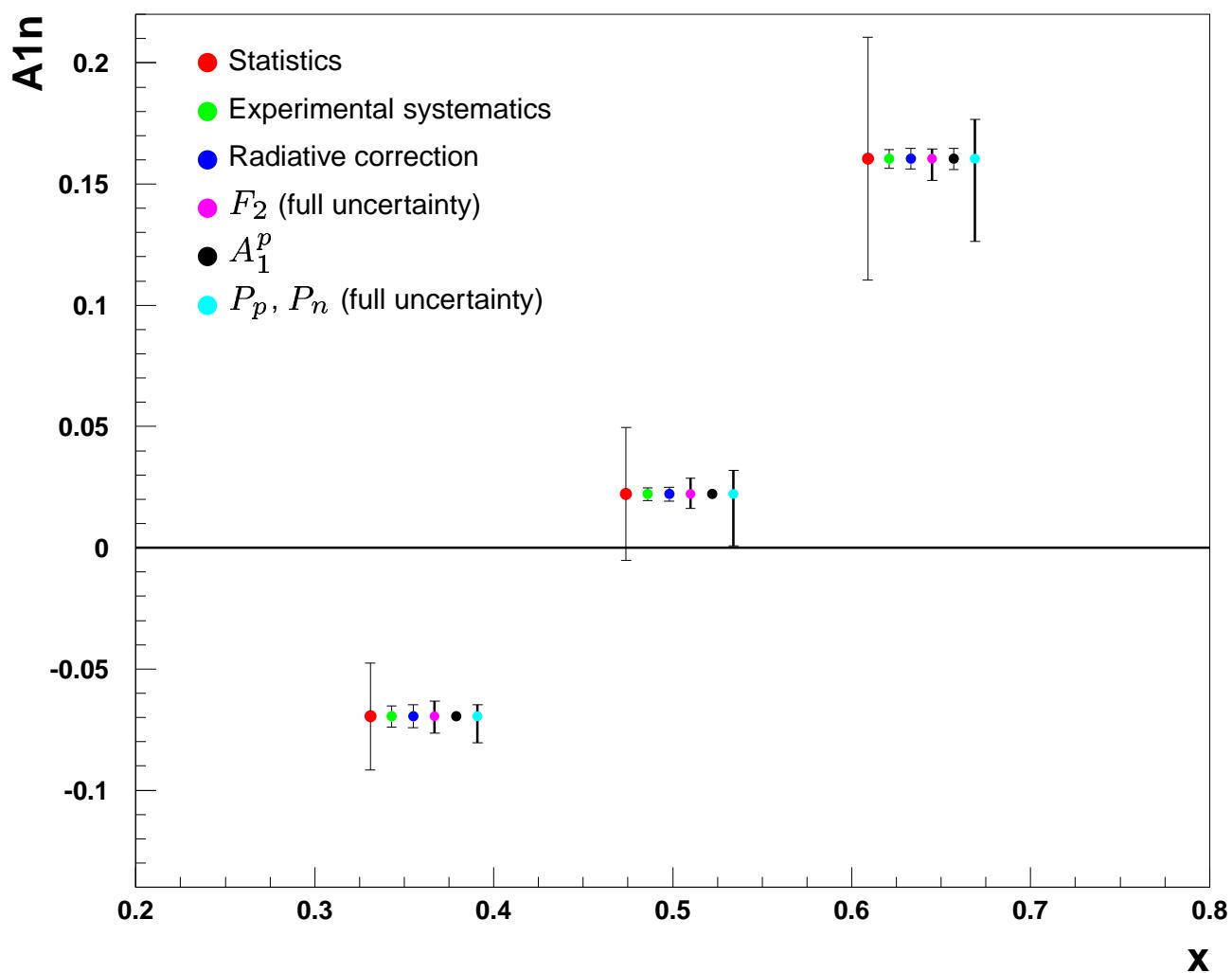
RADIATIVE CORRECTION

- Correct $A_{||}^{^3He}$, $A_{\perp}^{^3He}$ directly;
- F_2 variation (5 models), $F_2^{p,\text{res}}$ (2);
- g_1 variation, g_1/F_1 variation (3), $g_1^{^3He,\text{res}}$ variation;
- g_2 variation (g_2^{ww} vs. $g_2 = 0$);

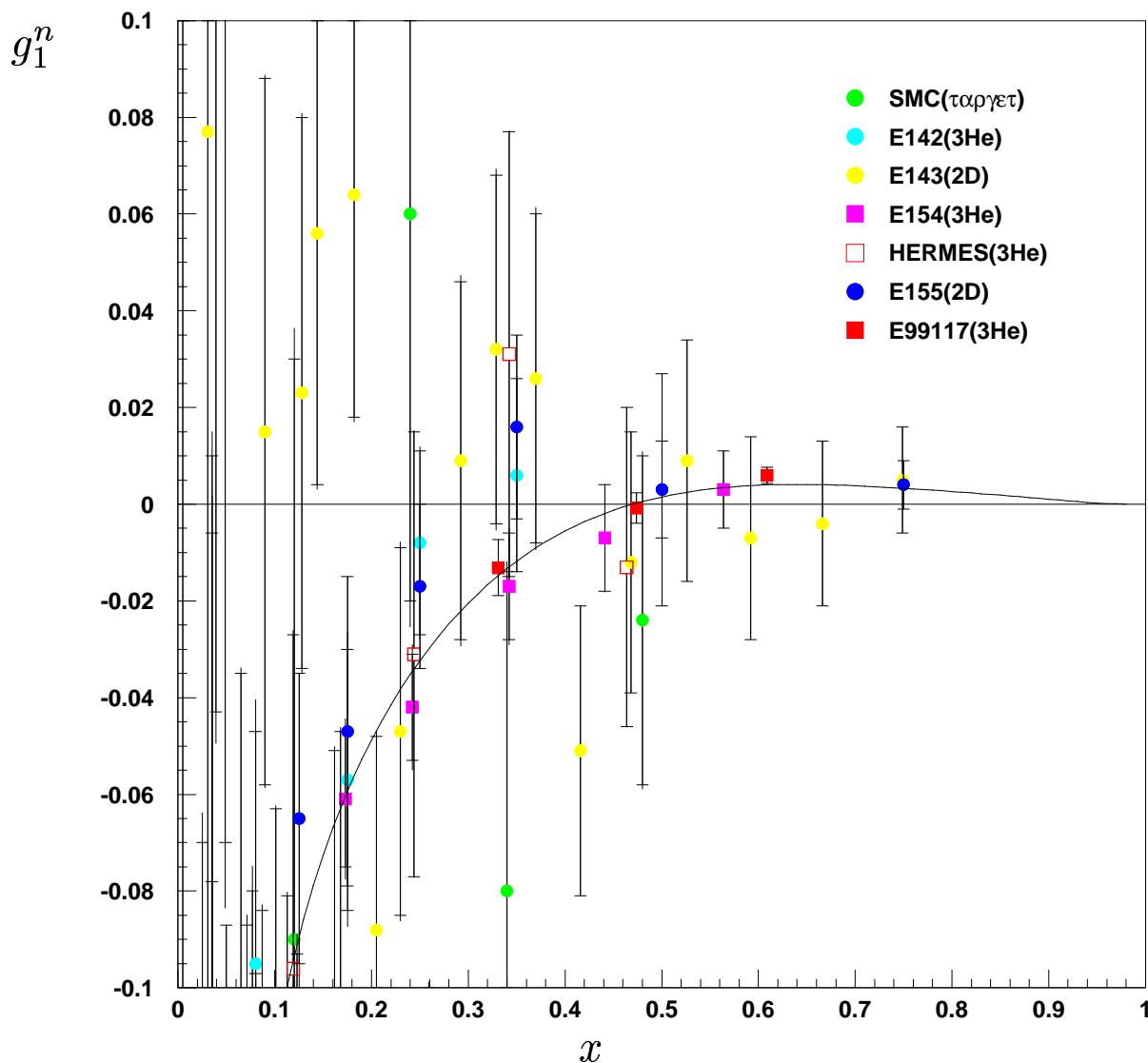
NUCLEAR CORRECTION

- F_2^p , F_2^d ; $\mathcal{R}^{^3He}$, \mathcal{R}^D ; A_1^p ; P_p , P_n

Error Analysis

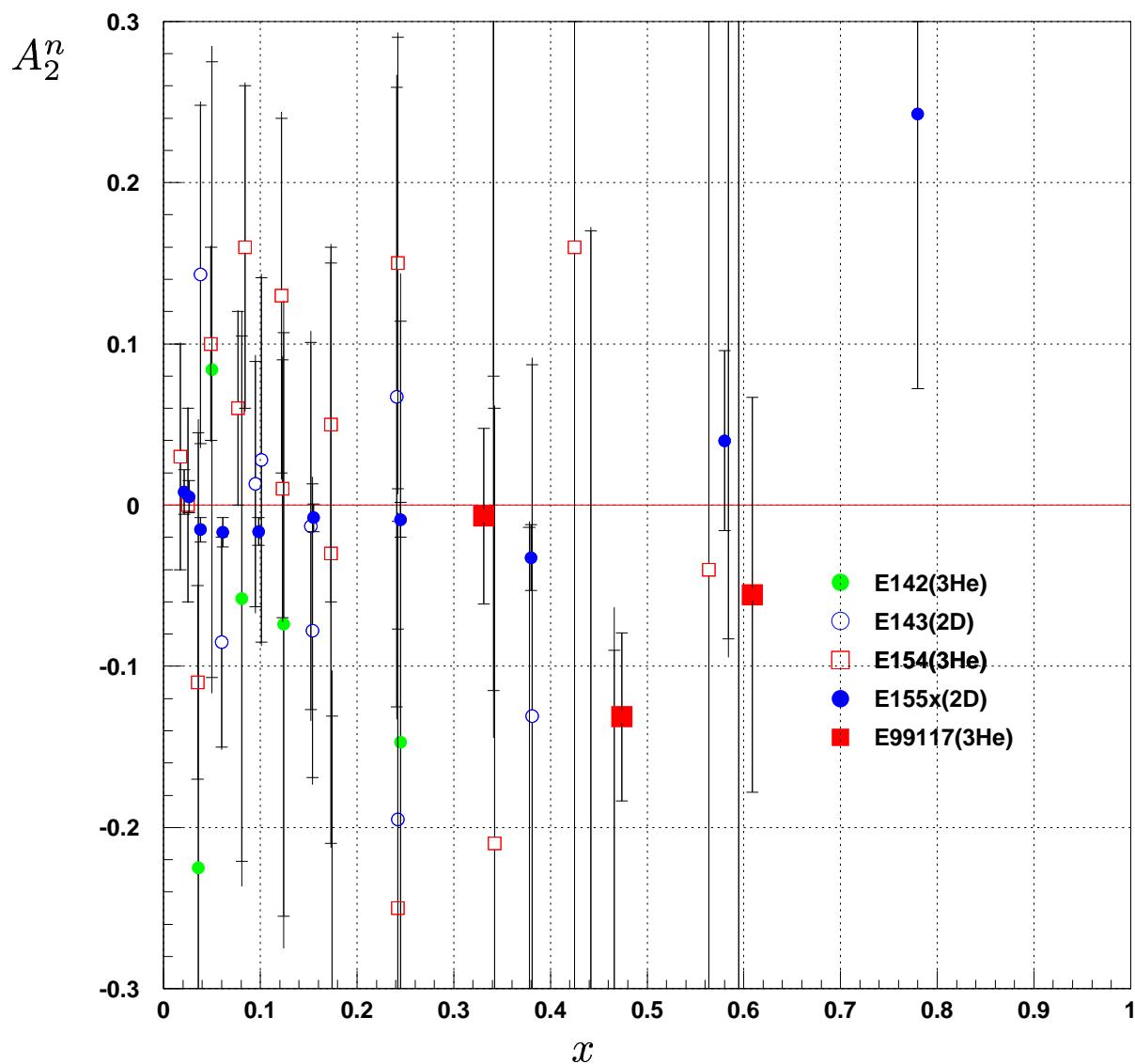


Preliminary Result

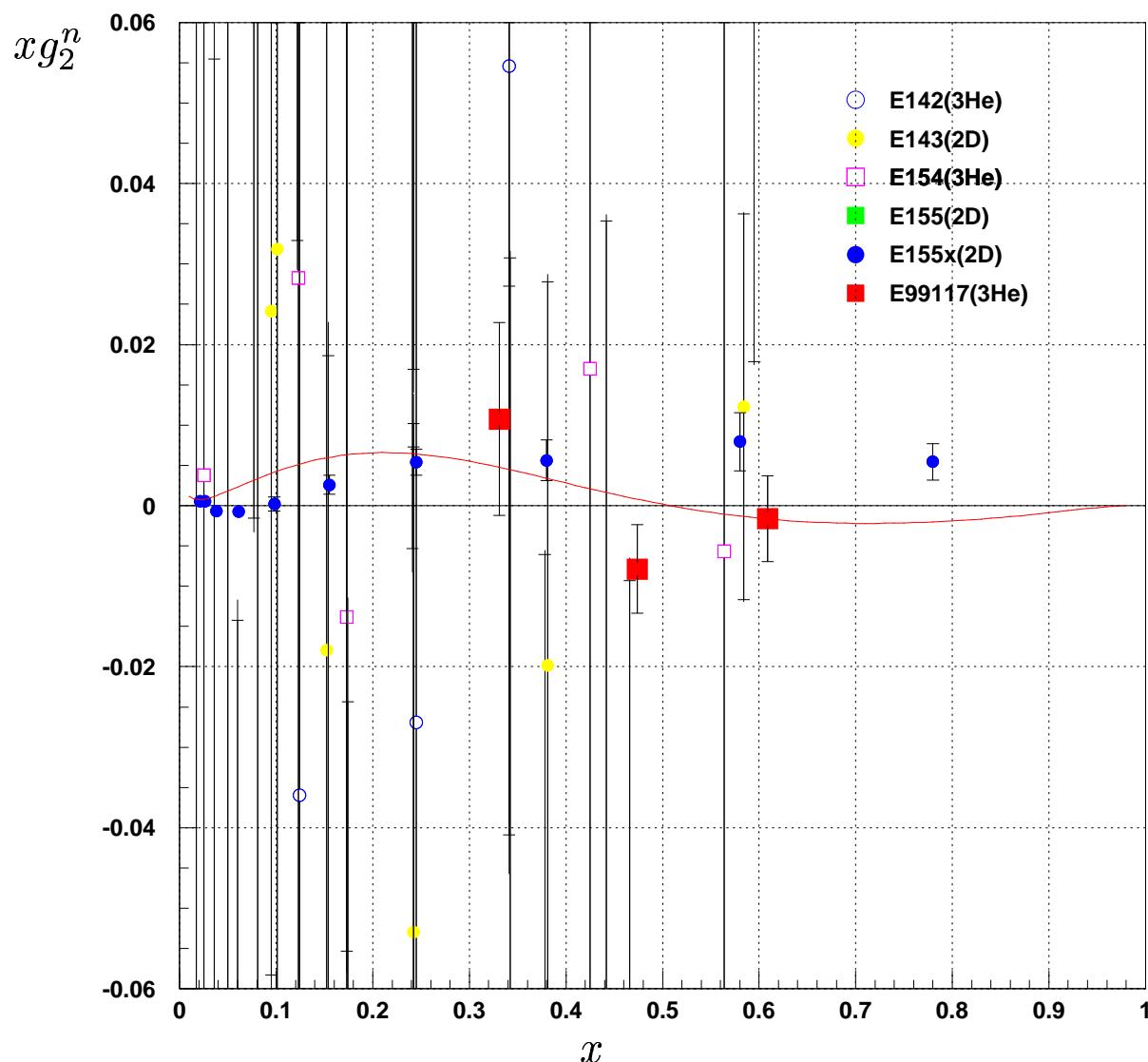


black solid curve: g_1^n obtained from E155 fit for $\frac{g_1}{F_1}$ and NMC95 fit for F_1 , at $Q^2 = 4.0$ (GeV/c) 2

Preliminary Result



Preliminary Result



red solid curve: xg_2^{ww} obtained from E155 fit for $\frac{g_1}{F_1}$ and NMC95 fit for F_1 , at $Q^2 = 4.0$ (GeV/c) 2

Discussions

A_1^n AND SPIN CRISIS

- Proton spin 'crisis': $\Sigma = \Sigma_v + \sum \Delta(q + \bar{q})_{sea} \sim 0.3 \pm 0.1$
- Current understanding of nucleon spin:
 - $\Sigma_v = 0.75$ from rCQM;
 - $\sum \Delta(q + \bar{q})_{sea} = -0.45$ from data;
 - $1 = \underbrace{\Sigma_v + \sum \Delta(q + \bar{q})_{sea}}_{\Sigma=0.3\pm0.1} + 2L_q + \Sigma_G$
- Spin physics programs have been planned at HERMES, RHIC and CERN to study $\Delta\bar{q}$ and ΔG ;
- Measuring $\Delta\bar{q}$ and ΔG is also based on the knowing of contribution from valence quarks;
- A_1^n and A_1^p at large x will check our valence quark picture of $\Sigma_v = 0.75$. A negative A_1^n will bring a great doubt at this assumption and thus start a new search for resolution of 'spin crisis'.
- Can also check pQCD at valence quark region. ($\frac{\Delta d}{d} \rightarrow ? 1, -\frac{1}{3}$)

Summary

EXPERIMENT E99-117

- Provides the first precise data of A_1^n and g_1^n at $x > 0.4$;
- Data on A_2^n , g_2^n also available;
- Check current understanding of nucleon spin;
- Help to understand constituent quark models;
- Provide new constraint on other models, PDFs.

Summary

NEUTRON SPIN STRUCTURE PROGRAM AT JLAB HALL A

(USING POLARIZED 3He)

Sum Rules

- E94010 A Connection between Bjorken and GDH Sum Rules, (Nov~Dec 1998)
- E97110 The Generalized GDH Sum Rule for Nearly Real Photons (Sep 2002)

Spin Structure Functions

- E99117 Neutron Asymmetry A_1^n at largert x_{Bj} (June ~ July 2001)
- E97103 Search for Higher Twist Effect in g_2^n (Aug ~ Sep 2001)
- E01012 Neutron Spin Structure in the Resonance Region (approved)

A_1^n @ JLAB 12 GEV UPGRADE

- Precision measurement of spin asymmetry in valence quark region
- Decisive test of pQCD vs quark model, insight to quark-gluon wavefunctions

